Docket No.: 1794-0141P
(PATENT)

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Patent Application of:
Yoshinobu AOYAGI et al.

Application No.:	09/941,612	Confirmation No.:	6758
Filed:	August 30, 2001	Art Unit:	1792
For:	IMPURITY DOPING METHOD FOR SEMICONDUCTOR AS WELL AS SYSTEM THEREFOR AND SEMICONDUCTOR MATERIALS PREPARED THEREBY	Examiner:	M. SONG

DECLARATION UNDER 37 C.F.R. §1.132

MS Amendment
Commissioner for Patents
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Sir:

I, Hideki Hirayama, residing at 3-20-37 Oka, Asaka, Saitama 351-0198 Japan, do declare and say as follows:

1. I am a citizen of Japan and am familiar with the subject matter of the above identified application (U.S. Application No. 09/941,612) of which I am a contributing inventor.

2. In the Examiner's Office Action dated October 29, 2009, the Examiner rejects claims 37 and 39-43 under 35 U.S.C. § 102(b) as being anticipated by Kobayashi, U.S. Patent No. 4,829,022, rejects claims 37-43 under 35 U.S.C. § 103(a) as being unpatentable over Nishizawa, U.S. Patent No. 5,693,139, in view of Kobayashi, and rejects claim 44 under 35 U.S.C. § 103(a) as being unpatentable over Nishizawa in view of Kobayashi, and further in view of Edmond, U.S.

Patent No. 5,739,554, and Manabe, U.S. Patent No. 6,472,690. I do not agree with the Examiner's rejections for the following reasons.

3. With respect to Kobayashi, the Examiner alleged that the claimed invention has no patentability because (1) beryllium and silicon are supplied as p-type dopant and n-type dopant together with atoms of group III all at once thereby to form Be-Si pairs in the layer of the group III, and (2) impurity pairs are formed by doping two types of impurities wherein the two types of impurities are doped irrespective of whether or not they are doped at the same time. However, the important difference between the claimed invention and Kobayashi resides in whether dopants of p-type impurity and n-type impurity are doped at the same time or not, i.e., whether they are doped in time interval difference mode or not. In fact, a remarkable difference in advantageous effects is caused by the difference between a doping mode wherein dopants of p-type impurity and n-type impurity are doped **at the same time** and another doping mode wherein they are doped **in a time interval difference**.

4. As seen hereinbelow, a case where a plurality of impurities are supplied non-concurrently (the present invention) and another case where a plurality of impurities is supplied concurrently (Kobayashi) are described in detail.

4.1. Non-concurrent supply of impurities: Technique according to the present invention.

In the present invention, the pulse sequence shown in FIG. 7 is a sequence of co-doping by which Mg and Si are not introduced at the same time, but non-concurrently introduced so as to array them side-by-side (molecular co-doping). The sequence uses such an effect that "Si atoms repel Ga atoms" by which advantageous effects have been apparently obtained from our experimental results.

In the sequence as described above, Mg-Si pair is formed in a manner described hereunder by referring to **FIG. A** (see **Attachment**).

First, Ga and Mg are supplied to effect growth of several atom layers in which Ga is doped with Mg. In this case, supply amounts of Ga and Mg are in such that Ga corresponds to several atom layers and Mg is in the doping level.

In this stage, Mg distributes homogeneously into a Ga layer, and a position of Mg atom is fixed in Ga atom to be deposited. In such a way, the position of Mg in the Ga layer is settled.

Then, when Si is solely flowed on the Mg in the Ga layer, Si repels Ga to become close to Mg, so that Si approaches Mg. As a result, they are arrayed side-by-side.

Furthermore, ammonia is flowed with respect to the several atom layers formed as described above to be nitrided at a stroke to crystallize them, whereby a semiconductor crystal is obtained.

More specifically, as shown in FIG. A, scattered Si approaches Mg in a Ga layer, whereby Si and Mg are arrayed side-by-side to produce Mg-Si pairs. As a result, GaN crystal which is **co-doped molecularly with Si and Mg** is produced.

4.2. **Concurrent** supply of impurities: Technique according to Kobayashi

In case of concurrent supply of impurities as shown in Kobayashi, advantageous effects of the production of Mg-Si pairs as in the present invention as described above are barely observed. In other words, effects of the production of Mg-Si pairs decrease remarkably in the concurrent supply of impurities as in the technique of Kobayashi.

As seen hereinbelow, a case of concurrent supply of impurities as shown in Kobayashi will be described by referring to **FIG. B** (See **Attachment**)

First, Ga atoms are deposited in an amount corresponding to several layers, and Si is supplied concurrently with Mg to the layers. As a result, both Si and Mg are homogeneously distributed into Ga, whereby Si and Mg are discretely put in position **without** maintaining side-by-side array relationships. Accordingly, there is no advantageous effect of development in particular side-by-side array relationships between Si and Mg. In other words, Mg-Si pairs are barely produced.

Then, ammonia is flowed with respect to the several atom layers formed as described above to be nitrided at a stroke, whereby a semiconductor crystal which is discretely doped with Mg and Si; i.e., the semiconductor crystal where dopants are crystallized while **maintaining their non-molecular state** is obtained.

Furthermore, when Ga, Si, and Mg are supplied all at once, Mg becomes easily close to Si, because Si and Ga are hardly close to each other. However, each concentration of Si and Mg (feed ratio of atoms) is around one-hundred thousandth in comparison with concentration of Ga. Therefore, it is not expected that Mg and Si come to be close to each other. Accordingly, it is considered there is such scarce advantageous effect that Si and Mg are arrayed side-by-side to produce Mg-Si pairs as in the case of non-concurrent supply of impurities (the present invention).

5. As mentioned above, there is a clear difference between the non-concurrent supply of impurities according to the present invention and the concurrent supply of impurities by Kobayashi. Therefore, semiconductor crystals produced by both the techniques are quite different from each other. In other words, Si and Mg are not arrayed side-by-side in Kobayashi; otherwise, positions of Mg atoms are fixed preliminarily in Ga layers, so that repelling effects caused in between Ga and Si are used, and in this condition, Si is supplied. Namely, such a manner as in the present invention that a Ga film doped with Mg is preliminarily formed, and then, the resulting film is doped with Si is the only method by which molecular co-doping can be effected.

6. According to the GaN crystal co-doped molecularly with Si and Mg of the present invention, the accepter level can shallow. In other words, the accepter level cannot shallow in a crystal doped discretely with impurity atoms. On the other hand, when impurities are introduced into a crystal in the form of molecule, the resulting shallow effects for the accepter level become remarkable. More specifically, the respective wave functions of two types of elements are not overlapped with each other in the two types of elements doped discretely as in the manner of Kobayashi. Accordingly, the accepter level does not shallow as a result of doping two types of elements. However, in such a case as in the present invention that Mg and Si are co-doped molecularly side-by-side; the respective wave functions are overlapped with each other, so that accepter level can shallow due to doping of two types of elements. Therefore, in the present invention, the accepter level of a shallow rank order is newly formed, whereby activation energy decreases, and the number of carrier increases, resulting in improvements of conductivity.

7. As described above, the present invention adopts a manner of molecular co-doping in case of producing a crystal. This feature is clearly absent from Kobayashi. Even if the technique shown in Kobayashi were so-called "co-doping" which means doping of a plurality of atoms, assuming *arguendo*, this is not "molecular co-doping" which means atoms exist molecularly as in the present invention. Therefore, the technique by Kobayashi differs from that of molecular co-doping. In other words, Kobayashi's technique is quite different from that of the present invention. Accordingly, the Examiner's rejections of the claim 37 and its dependent claims are improper and should be reconsidered and withdrawn.

8. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

By Hideki Hirayama
Hideki Hirayama

March 25, 2010
Date

Attachment: Illustration of Non-Concurrent Supply of Impurities & Concurrent Supply of Impurities